



6.0 Synthesis of Results

The objective of the screening assessment was to identify areas where the greatest potential exists for adverse effects on humans or the environment under current conditions. This required determining what contaminants are elevated because of past or ongoing Hanford Site operations, and, if those contaminants are elevated, what is the measure of potential risk to both humans and the ecosystem.

With the above in mind, the following assessment questions were established:

- ◆ Do current levels of contaminants in Columbia River water, sediment, and riparian zone materials pose a potential risk to ecological resources?
- ◆ Do current levels of contaminants in Columbia River water, sediment, and riparian zone materials pose a potential risk to humans who might be exposed to them?

If the answers to either of these questions were yes, then answers for the following sub-set of questions were sought:

- ◆ What contaminants contribute to risk? (For answer, see Figure 6.1 and Table 6.1.)
- ◆ Where in the study area are these contaminants located? (For answer, see Figure 6.1 and Table 6.1.)
- ◆ In what media are these contaminants concentrated? (For answer, see Table 6.1.)
- ◆ Which organisms or groups of organisms have the greatest likelihood of being adversely affected? (For answer, see discussion below in Section 6.3 and Table 4.22 in Section 4.2.)
- ◆ Humans in which economic or cultural categories have the greatest likelihood of being adversely affected? (For answer, see discussion below in Section 6.3 and Figure 5.4 in Section 5.2.)

6.1 Assessment Context

By agreement with the Tri-Parties and the CRCIA Management Team, this screening assessment addressed the current potential for ecological and human risk, resulting from known levels of contaminants in the Columbia River or in its immediate vicinity. The screening assessment does not address inventories currently moving towards the river from distant locations or other inventories that may be left by future remediation activities at other Hanford Site locations.

The contaminants that could possibly be associated with past Hanford Site operations were evaluated. This contaminant identification process, described in Section 2.2, was based on a preliminary review of easily available records, environmental measurements, and process knowledge. The initial list contained nearly 100 possible environmental contaminants. Although a considerable effort was expended to compile this list, its use was to focus the remaining data gathering on only those contaminants of greatest interest. The data and parameters used in the selection of contaminants for study were not the ones used in the remainder of the screening assessment because the data and parameters used for the risk assessment could only be determined once the contaminants were selected.



Figure 6.1. Summary of the Screening Assessment of Risk to the Ecosystem and Human Health (The reporting thresholds in this figure identify potentially hazardous contaminants, chronic and acute effects to all plants and animals, and toxic and carcinogenic impacts on human health for all scenarios considered in this report.)

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Table 6.1. Potentially Hazardous Contaminants Identified by River Segment and Contaminating Media
(This table presents the contaminants by river segment and media and the estimated range of human risk.)



	Ecological Risk		Human Risk					
	River		River		Ranger Scenario		Native American Sc.	
Contaminant	Segment	Medium	Segment	Medium	Haz. Index	Risk	Haz. Index	Life Risk
Benzene			5	SP				2.60E-05
			13	SP				2.60E-05
Carbon-14			4	SP				2.90E-05
			6	SP				1.20E-05
Cesium-137			2	SW				7.01E-06
			3	SW(2)				7.46E-06
			4	SW(2)				1.06E-05
			5	SW(2)				1.32E-05
			6	SW				1.76E-05
	7	SD	7	SW(6)				2.16E-05
			8	SW				2.78E-05
			9	SW(8)				2.81E-05
	10	SD	10	SW(8)				3.06E-05
			11	SW(8)				2.94E-05
	12	SD	12	SW(8)				2.92E-05
			13	SW(8)				3.32E-05
			14	SW(8)				2.43E-05
			15	SW(8)				2.39E-05
			16	SW(8)				2.63E-05
			18	SW				1.34E-05
			19	SW(18)				2.05E-05
			21	SP(GW)				1.59E-05
Chromium	2	SD+SP	2	SW+SD		2.60E-04	2.32E-02	2.58E-01
	4	SD+SP	4	SD+SP		2.10E-04	3.30E-02	1.09E-01
	5	SD+SP	5	SD		2.10E-04	1.43E-02	6.30E-02
			6	SW		5.90E-05		4.23E-02
			7	SD		1.50E-04		6.94E-02
			8	SW+SP		5.60E-05	1.35E-02	8.66E-02
	9	SD+SP	9	SD+SP		1.00E-04	2.46E-02	6.72E-02
	10	SD+SP	10	SD+SP		1.40E-04	1.71E-02	5.90E-02
			13	SD		7.20E-05		5.28E-02
			18	SD		1.90E-04		3.89E-02
			19	SD		2.50E-04		1.05E-01
			20	SD		1.60E-04		7.03E-02
			27	SD		1.50E-04		1.64E-02
Cobalt-60			2	SD				3.54E-06

	Ecological Risk		Human Risk					
	River		River		Ranger Scenario		Native American Sc.	
Contaminant	Segment	Medium	Segment	Medium	Haz. Index	Risk	Haz. Index	Life Risk
(Diffuse)			3	SW(2)				2.22E-06
			4	SW(2)				2.96E-06
			5	SW(2)				2.71E-06
	6	SD	6	SD				1.08E-05
	7	SD	7	SD				2.58E-06
	8	SD	8	SW				3.71E-06
	9	SD	9	SD				2.49E-06
			10	SW(8)				1.86E-06
			11	SW(8)				2.16E-06
	12	SD	12	SW(8)				2.04E-06
	13	SD	13	SP(GW)				6.61E-06
			14	SW(8)				1.55E-06
			15	SW(8)				2.08E-06
			16	SW(8)				2.08E-06
			17	SP				2.15E-06
			18	SW				3.49E-06
			19	SW(18)				8.46E-06
			21	SP(GW)				2.89E-06
Copper	4	SP	4	SD			2.35E+00	
			11	SD			2.57E+00	
			14	SD			2.79E+00	
			17	SD			2.51E+00	
	20	SP						
			23	SW			6.51E+00	
			24	SW(23)			4.28E+00	
			25	SW(23)			6.32E+00	
			26	SW(23)			5.30E+00	
			27	SW(23)			6.90E+00	
Cyanide	20	SP(GW)						
	21	SP(GW)						
Europium-152			13	SP(GW)				6.30E-05
Europium-154			6	SP				2.92E-06
			8	SP				9.23E-06
			13	SP(GW)				1.26E-05

	Ecological Risk		Human Risk					
	River		River		Ranger Scenario		Native American Sc.	
Contaminant	Segment	Medium	Segment	Medium	Haz. Index	Risk	Haz. Index	Life Risk
			17	SW				3.13E-06
			18	SW(17)				3.15E-06
			20	SP				1.68E-06
			21	SP(GW)				1.47E-05
Iodine-129			19	SP(GW)				2.20E-06
Lead	2	SD+SP						
	3	SD+SP						
			4	SD			4.30E-01	
	5	SD+SP	5	SD			3.65E-01	
	7	SD+SP						
	9	SD+SP						
	13	SD+SP						
	17	SD+SP	17	SD			1.22E+00	
	19	SD+SP	19	SD			6.47E-01	
	20	SD+SP	20	SD			4.74E-01	
	21	SD+SP						
			22	SW(21)			3.78E-01	
Mercury	3	SD						
	4	SD						
	6	SD						
	8	SD						
	9	SD						
	10	SD						
	12	SD						
	13	SD						
	14	SD						
	15	SD						
	16	SD						
	19	SD+SP						
	20	SD+SP						
Neptunium-237			8	SD				6.50E-05
			9	SD				8.30E-05
Nickel	20	SD						

	Ecological Risk		Human Risk					
	River		River		Ranger Scenario		Native American Sc.	
Contaminant	Segment	Medium	Segment	Medium	Haz. Index	Risk	Haz. Index	Life Risk
Nitrates			4	SP			1.56E-01	
			10	SP			1.05E-01	
			12	SP(GW)			8.88E-02	
			14	SP			1.42E-01	
			17	SP			1.38E-01	
			20	SP			2.39E-01	
Nitrites			19	SP			1.08E-02	
Strontium-90			2	SD				8.35E-06
			3	SD				6.72E-05
			4	SW(3)				1.07E-05
			5	SD				1.28E-04
			6	SD				6.72E-04
			8	SP				1.79E-05
			9	SW				1.41E-05
			10	SD				1.10E-04
			12	SW(10)				6.43E-06
			13	SD				4.38E-05
			15	SD				5.95E-05
			16	SW				2.97E-05
			20	SW				6.09E-06
			21	SW				5.36E-06
			24	SW(21)				6.45E-06
			26	SW(21)				5.83E-06
			27	SW(21)				6.57E-06
Sulfates			7	SP(GW)			1.14E-02	
Technetium-99			3	SD				2.84E-06
	8	SD	8	SD				1.18E-06
	9	SD	9	SD				9.61E-07
	10	SD	10	SD				2.80E-06
	14	SD						
			17	SD				1.34E-06
	19	SD	19	SD				2.51E-06
Tritium (Hydrogen-3)			2	SP				1.31E-05
			4	SP(GW)				6.70E-06

[illegible]

The initial list of potential contaminants was screened, using a multi-stage screening process described in Section 2.3, to a manageable number of contaminants likely to produce the greatest risk to the environment or human health. This process was based on a set of simple exposure equations for people and biota. The final list was established to provide reasonable assurance that the preponderance of the risk of either acute toxicity or long-term carcinogenicity of humans and of either acute toxicity or long-term survival of aquatic biota was addressed. Additional considerations were given to known sources of radiation and radioactive materials.

The spatial domain and spatial scale of the analyses were established in consultation with the CRCIA Team. The agreed focus was on the Hanford Reach of the Columbia River and the areas immediately downstream as far as McNary Dam. To best represent the current environmental conditions and state of knowledge relative to contaminant concentrations in the Columbia River, the study area was divided into 27 segments along the river. The segmentation also provides meaningful information associated directly with the site operable units that will be useful in evaluating future remedial actions.

Although the primary focus is on the Columbia River and its associated riparian zone, the potential for influx of contaminants via groundwater through seeps and springs was addressed by relying on additional



measurements of the potential contaminants in groundwater some distance inland from the river shoreline. Depending on the availability of groundwater measurements, this distance varies up to 0.8 kilometer (0.5 mile), the larger distances corresponding to areas with fewer measurements. The segments range in length from less than 1 kilometer to more than 30 kilometers (0.5 to 20 miles). Even the smallest segments are too large to clearly distinguish small areas of highly elevated concentration (in other words, hot spots). Several such areas are known, and other specific studies address them. However, discovery of additional hot spots was not the focus of this assessment.

To gather the data to be used in the screening assessment (a separate process from that to determine which contaminants to study), a detailed search for environmental measurements was made. Hanford and non-Hanford sources were queried, including Hanford contractors, local municipalities, the States of Washington and Oregon, and federal agencies. Data were collected for measurements in the surface water of the Columbia River itself, river sediment, seeps and springs within the Hanford Reach, and Hanford Site groundwater. Only relatively current data were used, defined as being within the period from 1990 to present, in order to avoid evaluating problems that no longer exist. A large database was prepared. However, for many of the contaminants of interest in many locations, measurements were not available for the time period of interest. In these cases, a series of surrogation and extrapolation rules were devised to allow approximation of the local contamination levels. Where use of these approximations has identified a contaminant of potential hazard, the use of the surrogate values is highlighted to indicate the need for further confirmatory measurements. The final database is much larger and better substantiated than that used in the initial selection of contaminants to consider, but it is limited to those that were selected for evaluation.

Concurrently with the data gathering, the CRCIA Team established the indicators that would be used to judge the degree of hazard. For the ecological risk assessment, this consisted of defining a set of indicator species for which comparisons against toxicological benchmarks would be made. The selection of these indicator species has been defined in Section 4.1. For the human risk assessment, a suite of twelve human exposure scenarios was prepared. These have been described in Section 5.1. Individual calculations for each of these scenarios were compared with both toxicity and carcinogenicity indices. The exposure scenarios used cover a wide range of possible behavior patterns, but they are not all-encompassing. Additional possible ways that people could be exposed are easily postulated. Some of the scenarios used have parameters that are not currently possible because of restricted use of the site. These were included because the CRCIA Team wanted to examine whether certain types of possible future land use would pose a risk to such individuals, although they do not represent recommendations about future land uses.

Computational models were developed for all of the ecological species and human scenarios. The computational models include algorithms and input data to produce quantitative results. The computerized models and their parameters have been described in Sections 4.2 and 5.2 and are provided on diskettes in the appendixes. The models were tested and verified prior to their use.

The levels of the contaminants showed variability among and within environmental media and among and within individual river segments. In addition, there is uncertainty in almost all of the parameters used in the ecological and human exposure risk calculations. This implies that there is also considerable variability and uncertainty in the results.



To attempt to quantify the uncertainty, two calculation methods were used: deterministic and stochastic. For the deterministic method, the equations were calculated with single, high values of the parameters to identify potential worst case results. For the stochastic method, the equations were calculated with all possible combinations of parameter values, resulting in an output distribution rather than a single value. For the human risk calculations, both deterministic and stochastic results are available for contaminants in each of the river segments where data or substitute data were available. For the ecological risk analysis, the deterministic calculations were performed for all contaminant-species-segment combinations, but the stochastic calculations were only performed for those combinations for which it appeared that any risk was possible.

A benefit of the stochastic calculations was they enabled the results to be subjected to statistical comparisons. In these comparisons, the concentrations and resulting risk of the contaminants in each Hanford-influenced river segment could be compared to those upstream in Segment 1 that supposedly has not been influenced by releases from the Hanford Site. These comparisons gave insight into the nature and magnitude of the incremental risk posed by Hanford releases.

The ecological risk evaluated is for injury to individual plants or animals. The current state of scientific knowledge does not allow extrapolation to impact on the ecosystem with this level of information. Human risk is limited to individual toxic response or long-term carcinogenicity. The scenarios cannot address cultural impact or multigenerational impact of the exposures.

6.2 Influence of Data Gaps and Potential Future Parameters on the Results

The analyses completed for the screening assessment are based on the currently available data. Information is not available for all of the contaminants studied in all river segments. Where appropriate, data were extrapolated or surrogated to fill some of the data gaps, but other data gaps remain. The final results of the screening assessment, therefore, are limited by the available information. The assessment has indicated that there are portions of the Hanford Reach of the Columbia River in which concentrations of contaminants, particularly in sediment and groundwater, are high enough to warrant additional investigation and possible remediation. These river segments have been identified in this report. However, because of the data gaps, it is not possible to state that the concentrations of some of the contaminants in other locations are not also excessive.

The density of data that were available for the assessment is illustrated in Section 3.0. For some river segments, relatively few data are available. These are areas for which sampling could be advisable. However, the existing sampling schemes were developed with knowledge of past Hanford Site operations and the results of past sampling. In some instances, the lack of data for certain contaminants in certain locations is because those locations never gave cause to warrant sampling for those contaminants during the period 1990 to present. They may have been sampled earlier. Before a recommendation can be made for further sampling, consideration should be given to the results of past sampling not used in this analysis and the likelihood of acquiring useful information with additional sampling. Systematic radiological surveys have been made in the past (for example, Sula et al. 1980, EG&G 1990) that indicate the potential for finding additional, highly radiologically contaminated areas is small.



A further difficulty is that the spatial extent of the river segments as defined for the analysis is large enough to partially mask the presence of hot spots. The risk results tend to average out over segments as much as a few miles long. While it is quite unlikely that individual humans would choose to spend large portions of their time and derive most of their food from single point locations, it is likely that specific biota (particularly plants) could live their entire lives in one spot.

In tandem with the data gaps is the fact that the scenarios used to establish the potential for human exposure, defined in Section 5.1, all have a common starting assumption: the individual described performs all of the described activities within the selected segment and within the river or immediately adjacent riparian zone. In many locations along the riverbanks of the study area, the riparian zone is quite narrow. The likelihood of a person's actually deriving all of her or his food and water from this narrow strip of land has not been included in the scenario definitions. However, to simplify the analyses and provide a common basis for comparison, the same assumptions have been used for all river segments. It is recognized that the screening assessment has been performed with scenarios that include parameters not currently allowed because access to the site is restricted. These parameters are included because the CRCIA Team desired to determine if future potential uses of the land could pose risk to certain types of individuals. Before remedial activities are considered, site-specific considerations should be added to the general results presented here.

The screening assessment was designed to focus attention on those contaminants with the most immediate potential for human and ecological risk. However, some parameters included are future potential parameters. In addition, some data gaps have limited the assessment. Therefore, it is important to take into consideration the focus, the assumptions, and the limitations of this assessment when evaluating the results. Because a contaminant has been identified as potentially posing a risk does not necessarily mean that there is imminent risk to humans or the environment from this contaminant. Just as important, the converse may also be true. Because the risk of a contaminant in certain segments has not been identified does not necessarily mean that a risk does not exist. It just may not have been measured yet.

6.3 Screening Assessment Results and Conclusions

The results of the screening assessment are provided in Section 4.2 for the ecological risk and Section 5.2 for the human risk. These sections show that when taken in the context of the screening assessment the answers to the two main assessment questions are yes. Environmental levels of some contaminants do appear to be elevated as a result of Hanford Site operations as well as resulting from other human activities upstream in the Columbia Basin. Both the ecological modeling and human exposure simulations identify contaminants and locations for which risk to both the environment and humans is evident and for which further analyses or measurements would be worthwhile.

Figure 6.1 is a high-level summary of the findings of the ecological risk and human health risk assessments. The contaminants and affected segments of the Columbia River that pose a potential risk according to the results of either the ecological or human risk assessments are identified. The overlapping results of the two assessments are also identified. For most of the contaminants, segments identified by the ecological risk analysis were also identified by the human health analysis, but sometimes the contaminants were in media that affect biota more directly than humans, so that human risk for those contaminant-segment



combinations is below the reporting threshold. Conversely, segments identified via the human health analysis having indications of increased potential risk are not always identified in the ecological analysis.

The reporting thresholds used in Figure 6.1 to identify potentially hazardous contaminants include consideration of chronic and acute effects on the environment and toxic and carcinogenic impact on humans. For the chronic ecological effects, a contaminant is identified if the number of stochastic simulation results exceeding a chronic toxicity benchmark is more than 5 percent greater than the number estimated in the background segment for that contaminant (denoted by yellow in Figure 4.19 of Section 4.2). For acute ecological effects, a contaminant is identified as potentially hazardous if the sum of acute risk indices across all species for a contaminant is more than twice the equivalent total for the background segment (denoted by red in Figure 4.19 of Section 4.2). For humans, a contaminant is identified as potentially hazardous if the estimated hazard index for a given contaminant for any scenario is greater than 0.01 or if the estimated lifetime risk for any scenario is greater than 10^{-6} .

The contaminants identified in Figure 6.1 as potentially hazardous are listed in Table 6.1 with additional details about the magnitude and sources of the potential risk. Table 6.1 presents the contaminants of highest potential risk identified in either the ecological risk assessment or the human health risk assessment, the segments in which they were identified, the medium or media which provided the dominating component of the risk, and the range of estimated human risk. To demonstrate the range of human risk, the median stochastic values of lifetime risk (carcinogenic chemicals and radionuclides) and hazard index (toxic chemicals) for both the Ranger and Native American Subsistence Resident scenarios are given. Table 6.1 then answers the first three subset questions of which contaminants at what location and in which media are a potential threat.

To answer the fourth sub-set question, the types of organisms most likely to be adversely affected were identified. Terrestrial species that are potentially most affected by contaminants in the study area are swallows, mallards, American coots, harvest mice, Canada geese, and raccoons. However, risk within the study area that is above background levels is limited to only a few locations within the study area (see Figure 4.22). The other species, including bald eagles, have relatively low risk in both absolute and relative (to background) terms. Aquatic species most likely to be affected by acute or chronic toxic effects from contaminants of Hanford Site origin are Columbia pebblesnail, hyalella, daphnia magna, crayfish, Woodhouse's toad, suckers, clams, mussels, and salmon/trout larvae. Most of these aquatic organisms have a benthic life style, spending all or a high proportion of their life in direct contact with sediment or pore water, and the pore water concentrations tend to drive their body burdens. A key pathway of exposure for the terrestrial organisms is predation of the aquatic species with high body burdens, which is also ultimately related to the concentration of contaminants in pore water.

To answer the fifth sub-set question, the categories of humans most likely to be affected were identified. Humans in the region of the Hanford Site may have a wide variety of exposures, from low to high. Generally speaking, the scenarios for the Fish Hatchery Worker, Industrial Worker, and Ranger have the lowest exposures and, therefore, are lowest in terms of health risk. As defined in Section 5.1, none of the people involved in these scenarios consume foods grown in the Columbia River riparian zone or drink seep water. Therefore, the exposures are mostly incidental external exposures and inhalation of resuspended materials, although the Fish Hatchery and Industrial workers also consume a moderate amount of Columbia River



water. The risk to workers from these pathways is quite low in comparison to those projected for people potentially exposed in other ways. At the other extreme, people postulated to live along the Columbia River, to eat substantial quantities of foods grown in the riparian zone, to eat fish and wildlife from the river, and to drink seep water have much larger potential exposures and, thus, estimated health risk. This category encompasses nearly all of the remainder of the scenarios described in Section 5.1. From a risk-assessment standpoint, very few differences appear between any of the Native American scenarios and recreational/residential scenarios. All postulate individuals who spend the bulk of their time in the vicinity and consume riparian-zone foods and drink untreated water.

Through the use of multiple exposure scenarios, the possible activities of people who could come into contact with the contaminants were evaluated. In general, risk to people today is low because of restricted access to the Hanford Site. Casual visitors and even people working in jobs associated with the Columbia River are not at risk unless they frequent limited areas and consume seep or spring water in which high concentrations of contaminants are present. However, potentially increased risk is possible if people were to move onto the Hanford Site and derive large percentages of their daily food intake from crops and animals in the river's riparian zone. In most instances, this higher risk is limited in extent to a few regions of highest contamination. Although there are numerous cultural differences between the general population and Native Americans, the common pathways of food and water consumption could affect both groups. These common pathways are the ones by which most exposure would be received. The key differences come in the source of the water and food products.

Because of scientific uncertainty, the overall potential impact on the riparian ecosystems is not known. There is insufficient knowledge about the distribution of species, their migration patterns, and their interactions over the entire Hanford Reach. It is possible to say that there is a risk to individual members of certain species, those that frequent the locations of highest contamination.

6.3.1 Hanford and Non-Hanford Sources of Contaminants

Contaminants for which a Hanford source appears to be indisputable include ammonia, cesium-137, chromium, cobalt-60, europium-152, europium-154, nitrates, strontium-90, technetium-99, tritium (hydrogen-3), and uranium isotopes. Other contaminants for which the Hanford Site may be a contributor, at least at specific locations, include copper, cyanide, lead, mercury, and zinc. The analyses indicate relatively high potential risk from these latter contaminants. However, the upstream risk from these contaminants is also high, and the Hanford Site increment over the upstream value is generally factors of two to three or less, making exact identification difficult.

As discussed in Section 4.2, there are sources of heavy metal releases to the Columbia River upstream of the Hanford Site. Thus, there are amounts of these metals, particularly chromium, copper, lead, mercury, and zinc, in sediment and water being transported through the Hanford Reach from operations, such as mining, upstream (Munn et al. 1995, Serdar 1993, Johnson et al. 1990). Recent events (Tri-City Herald 1997) have shown that upstream tributaries of the Columbia River may carry very high levels of metals, particularly during periods of high runoff. The concentrations are sufficient to be acutely toxic to wildlife. Contaminant metals tend to sorb to fine grained sediment, which deposit in slack water areas. Sizable quantities of sediment are deposited in the study area in the Hanford sloughs as well as behind both Priest



Rapids Dam upstream (a portion of Segment 1) and McNary Dam downstream (Segments 22-27). This sediment deposition with its relatively high concentrations of metals may help explain some of the results discussed below.

6.3.2 Uncertainty

Uncertainty is inherent in any risk assessment. The uncertainty within the ecological and human health assessments are discussed in Sections 4.2.10 and 5.2.3.3, respectively. Uncertainties include those associated with the exposure models, measured media data, representativeness of the data, use of surrogate and extrapolated data, exposure scenarios, accuracy of modeled processes, and toxicological and dose response references.

6.3.3 Potentially Hazardous Contaminants

The contaminants discussed in this section are those identified by the ecological and human health screening assessments to be potentially hazardous (see Figure 6.1 and Table 6.1). The intent of the following discussion of each potentially hazardous contaminant is to focus possible remedial decisions on those contaminants and media with the potential for the greatest risk reductions.

Benzene. Benzene is seen in low concentrations in seep water, frequently in conjunction with xylenes. It is a measurement surrogate for petroleum hydrocarbons. Some instances of petroleum contamination are known at the Hanford Site. The highest levels are seen at the 100-K and 100-F Areas. The primary exposure pathway is consumption of seep water.

Carbon-14. Carbon-14 is not detected in surface water. The Native American and Resident scenarios are uniformly controlled by ingestion of carbon-14 derived from seep water. Seep water was surrogated with groundwater in almost all segments along the Hanford Site. A single, particularly high value in the 100-K Area is evident in the deterministic data.

Cesium-137. Cesium-137 is a constituent of worldwide fallout and is present in soil and river sediment both upstream and downstream of the Hanford Site. Although in general the concentrations of cesium-137 in sediment are not greatly different from areas away from the Hanford Site, there is a greater variability in the measurements, indicating that a few localized zones of increased concentration exist. The primary risk is to biota that burrow into or live on the sediment. The primary pathway is external irradiation of these biota. For humans, the scenarios with high fish consumption show somewhat elevated risks from surface water, but this is largely driven by the surrogation process from a very few measured segments.

Chromium. This metal is identified as existing in elevated concentrations in several Hanford Reach river segments. For biota, the primary media of concern are sediment and pore water within the sediment (modeled using measurements of seep water or groundwater), and for humans the primary media are also sediment and the associated seeps. This indicates that the primary problem is groundwater contamination inland of the areas of the seeps, which is resulting in contamination of the sediment around the point where the groundwater issues into the river.



Cobalt-60. This radionuclide exists in both discrete particulate form and as generalized diffuse contamination. The particles have higher discrete activity and are somewhat easier to detect, but the more significant problem is with the diffuse sources. As with cesium-137, the primary ecological problem is direct external irradiation of biota that burrow into the sediment contaminated with diffuse cobalt-60 contamination.

Copper. In general, the risk to humans or biota from copper is similar above and below the Hanford Site. However, in absolute terms, this metal is one of highest risk to biota and humans. The modeling indicates that pore water (modeled using groundwater measurements) in the 100-K Area may be elevated, thus exposing biota. Copper is one of the metals that may also be enhanced from upstream sources.

Cyanide. The excess risk calculated for this chemical compound is associated with pore water (modeled using groundwater) for biota and with seep water (also modeled using groundwater) for humans.

Europium-152. Europium-152 is an activation product, similar in source to cobalt-60. Although discernible above background throughout the Hanford Reach in sediment, the risk to humans from europium-152 is primarily from ingestion of seep water in Segment 13.

Europium-154. Like europium-152, the activation product europium-154 is slightly elevated throughout the Hanford Reach. The primary exposures are via seep water, although the primary mechanism in Segments 17 and 18 is via surface water.

Iodine-129. Iodine-129 is detectable above background at very low levels in Hanford surface water, but the primary pathway of exposure is via drinking seep water. The only segment with concentrations measured sufficiently high to score over a risk of 10^{-6} is Segment 19.

Lead. The risk for lead to biota is dominated by concentrations in sediment and pore water, and the risk to humans is dominated by concentrations in sediment. Lead is one of the metals that may also be enhanced in sediment from upstream sources, but there are signs that lead may be somewhat enhanced in Hanford Site groundwater, particularly in the vicinity of the old Hanford townsite.

Mercury. The risk from mercury is primarily to biota from sediment. Mercury is one of the metals that may also be enhanced from upstream sources.

Neptunium-237. The only positive measurements for neptunium-237 occur in sediment in Segments 8 and 9, which in the modeling lead to small ingestion intakes. These are single point measurements and do not represent wide area contamination.

Nickel. The ecological modeling identifies nickel in sediment as a possible problem in the 300 Area only.

Nitrates. The risk to humans from nitrates is derived from the pathway of drinking seep water. Nitrates are known to be elevated in Hanford Site groundwater with samples in groundwater above the EPA drinking water standards in several of the reactor areas (see, for example, Dirkes and Hanf 1996).



Strontium-90. The primary risk to humans from strontium-90 comes from consuming foods grown in contaminated sediment. Risk from consumption of seep water comes in a close second. It is likely that the concentrations in the sediment are related to the seep water concentration at most of the locations that are coincident with reactor areas.

Sulfates. Sulfates are measured in surface water and seeps in numerous locations. The primary pathway is direct ingestion. The concentrations averaged in Segment 7 are slightly higher than elsewhere, but the risk from sulfates is generally low.

Technetium-99. Environmental concentrations of technetium-99 are not high, but the soil-to-plant uptake factor for technetium is very large. Vegetation has a strong propensity to concentrate technetium from soil. The key medium for technetium-99 is sediment. In the case of the ecological results, the risk is actually related to the chemical toxicity of technetium in plants. For the human health results, the risk is associated with consumption of food plants grown in the technetium-contaminated sediment in the riparian zone.

Tritium (Hydrogen-3). Tritium is widely distributed in Hanford Site groundwater. However, it has a low biological uptake and generally short retention time in plants and animals because it is associated with water. The primary route of exposure to humans is via consumption of seep water. The most extensive region where seep water contaminated with tritium enters the Columbia River is the vicinity of the old Hanford townsite.

Uranium-234/238. Although uranium is also ubiquitous in the environment, several areas have concentrations elevated above background levels. The media of interest include sediment and seep water near the 300 Area. A prominent pathway is the consumption of prey animals by animals farther up the food chain.

Zinc. The risk to biota is predominantly influenced by pore water and sediment. This metal provides the highest absolute contribution of risk to biota, but the median relative ratio to the upstream value is generally less than 1 for risk to humans. Zinc is one of the metals that may also be enhanced from upstream sources.